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BRUCE HEAVY WATER PLANT PROCESS DRAIN SURGE TANK (VESSEL 00-39204-TK303A) - FRACTURE MECHANICS ASSESSMENT OF BLISTER DAMAGE

Report No. 91-230-K

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ABSTRACT

A fracture mechanics assessment of two blister locations in a Bruce Heavy Water Plant process drain surge tank is described. The assessment is based on the CEGB "R6" procedure, applied to a postulated defect oriented normal to the principal stress direction. Results are presented in the form of allowable defect depth for a given safety margin. An attempt is made to reconcile the ASME Code Section VIII safety margins with those resulting from the "R6" procedure.

job	file	date	report no.
85-134	826.232	October 18, 1991	91-230-K

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EXECUTIVE SUMMARY

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Two blister locations were assessed using the CEGB "R6" method applied to postulated cracks oriented normal to the vessel wall. The method attempts to account for brittle and ductile failure mechanisms and their interaction.

The postulated cracks were intended as worst-case representations in which blisters might link forming a defect with projected area normal to the principal stress directions, or perhaps they might shield a defect from ultrasonic inspection.

Results are presented in the form of allowable defect depth for a given safety margin. The sensitivity of results to various analytical assumptions was studied.

Since explicit safety margins applicable to defects found during in-service inspection of these (non-nuclear) vessels are not provided by the ASME Boiler and Pressure Vessel Code, an attempt is made to reconcile the margins contained in the design Code (Section VIII Division 1) with the "R6" assessment method and nuclear code margins (ie, Section III and XI).

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TO: G.D. Davidson
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BRUCE HEAVY WATER PLANT PROCESS DRAIN SURGE TANK (VESSEL 00-39204-TK303A) - FRACTURE MECHANICS ASSESSMENT OF BLISTER DAMAGE

1.0 *INTRODUCTION*

A fracture mechanics evaluation of two blister locations in vessel 00-39204-TK303A (a "process drain surge tank") is presented. The assessment is based on the CEGB "R6" procedure/1-4/ applied to a postulated part-through-wall flaw.

Results are given in the form of allowable defect depth for a given safety margin. Since margins pertaining to a flaw evaluation are different from those in a design code, an attempt is made to reconcile the two.

2.0 *BACKGROUND*

A program to measure fracture properties of A516 Gr 70 plate including the effect of hydrogen and temperature is described in Reference 5. A summary of the assessment of the TK303A vessel, requested in Reference 6 was given in Reference 7. This report provides the details of that assessment.

3.0 *DIMENSIONS*

Relevant tank dimensions and blister locations are shown in Figure 1/8,9/. The evaluation was performed for wall thicknesses of 19.0 mm and 12.7 mm. These thicknesses bound the range of wall thicknesses of this vessel, with the latter representing a thickness reduction equal to the maximum corrosion allowance of 6.3 mm (0.25 in).

Figure 1 also shows the areas bounding the two blistered areas.

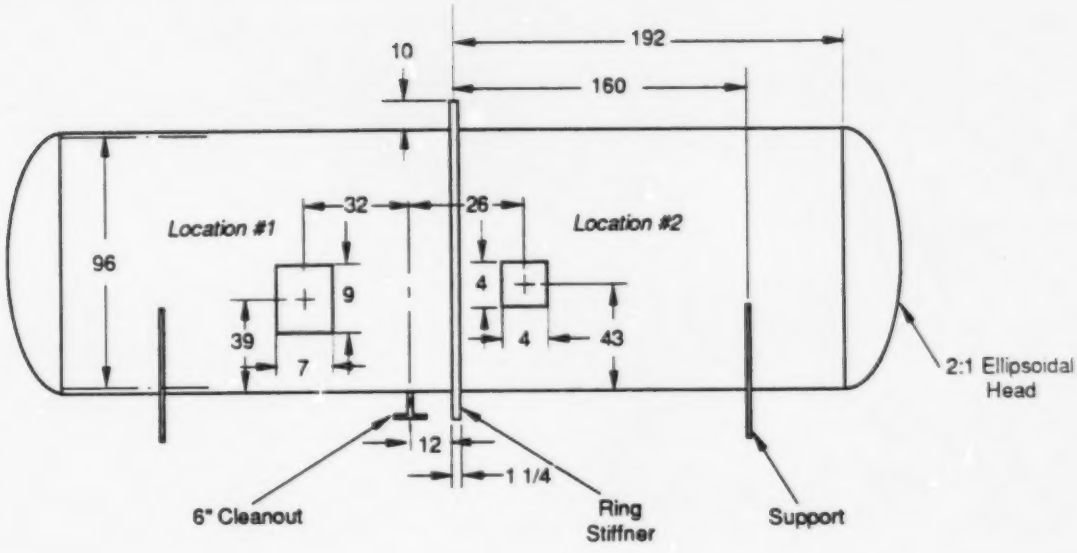


FIGURE 1

SCHEMATIC OF PROCESS SURGE TANK SHOWING BLISTER LOCATIONS (NB. Dimensions in inches)

186183 003 RD

4.0 *OPERATING AND DESIGN CONDITIONS*

Results were based on the following conditions/6,8/:

TABLE 1

OPERATING AND DESIGN CONDITIONS

	PRESSURE		*TEMPERATURE*	
	kPa	*(psi)*	*°C*	*°F*
operating	69	(10)	132	270 (max)
design	276	(40)	149	300

5.0 *MATERIAL PROPERTIES*

Tensile and toughness properties of the vessel plate material (A516 Gr 70) were taken from Reference 5. These were measured at two temperatures (21 and 145°C) using both hydrogen-charged and uncharged specimens.

Minimum and maximum values of yield, ultimate tensile and flow stress are given in Table 2.

TABLE 2

TENSILE PROPERTIES

	min (MPa)	*max (MPa)*
yield stress, σ_y	296	367
ultimate tensile stress, σ_u	482.6	530.0
flow stress, $\sigma_f = (\sigma_y + \sigma_u)/2$	389.3	448.5

The minimum value of initiation toughnesses for all test conditions reported in /5/ was 40 kN/m.

Young's modulus was taken to be 192.3 GPa, Poisson's ratio 0.3.

6.0 *STRESSES*

Stresses at the defect locations due to internal pressure and deadweight loading (due to liquid level) were obtained by finite element analysis using models similar to Figure 2. Finite element details are given in Appendix A. Detailed results are given in Appendix C.

Stresses due to internal pressure alone are virtually the same as those predicted by strength of materials, with the addition of a small through-wall bending component attributable to pinching by the ring stiffener.

Stresses due to liquid level deadweight loading arise primarily due to ovalization of the shell caused by bending as the tank sags between supports (ie, they are only indirectly associated with beam-type bending since the defects are near the bending neutral axis). Figure 3 shows that the ovalization axis shifts from vertical, for the "half-full" loading to horizontal for the "full" loading producing sign reversals in the axial membrane, and both the axial and hoop bending stress components (see Appendix C).

Since stresses vary considerably over the blister locations, the fracture analysis employed the maximum (membrane plus bending stress amplitudes with no regard to sign) for each loading condition (these are marked with asterisks in Appendix C). Maximum stresses are invariably associated with defect #2 at positions nearest the ring stiffener. Values extracted from the tables in Appendix C and used in the fracture evaluation are given in Tables 3 and 4.

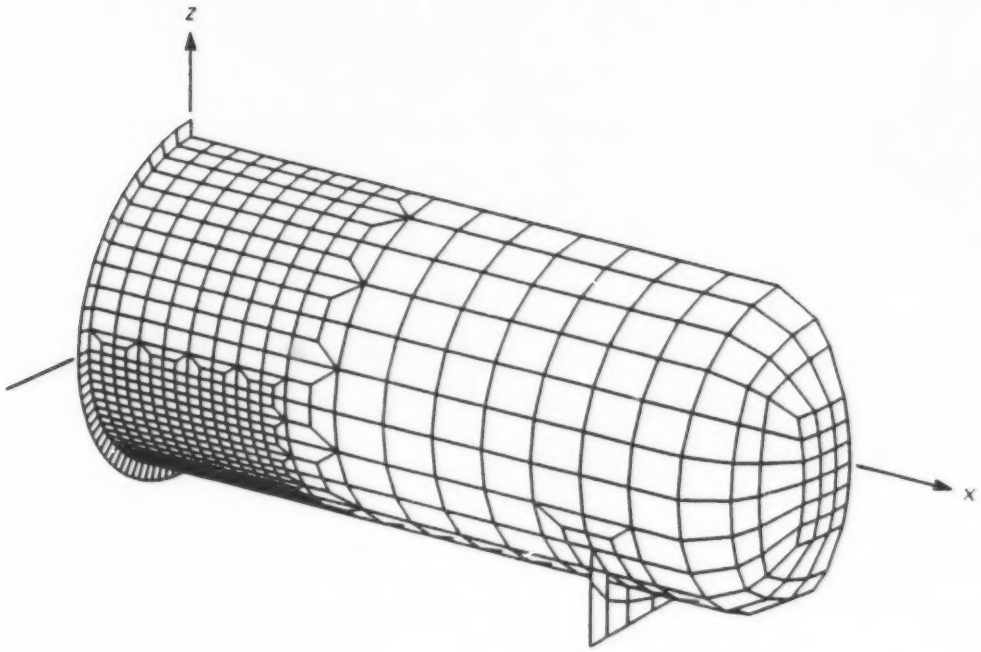
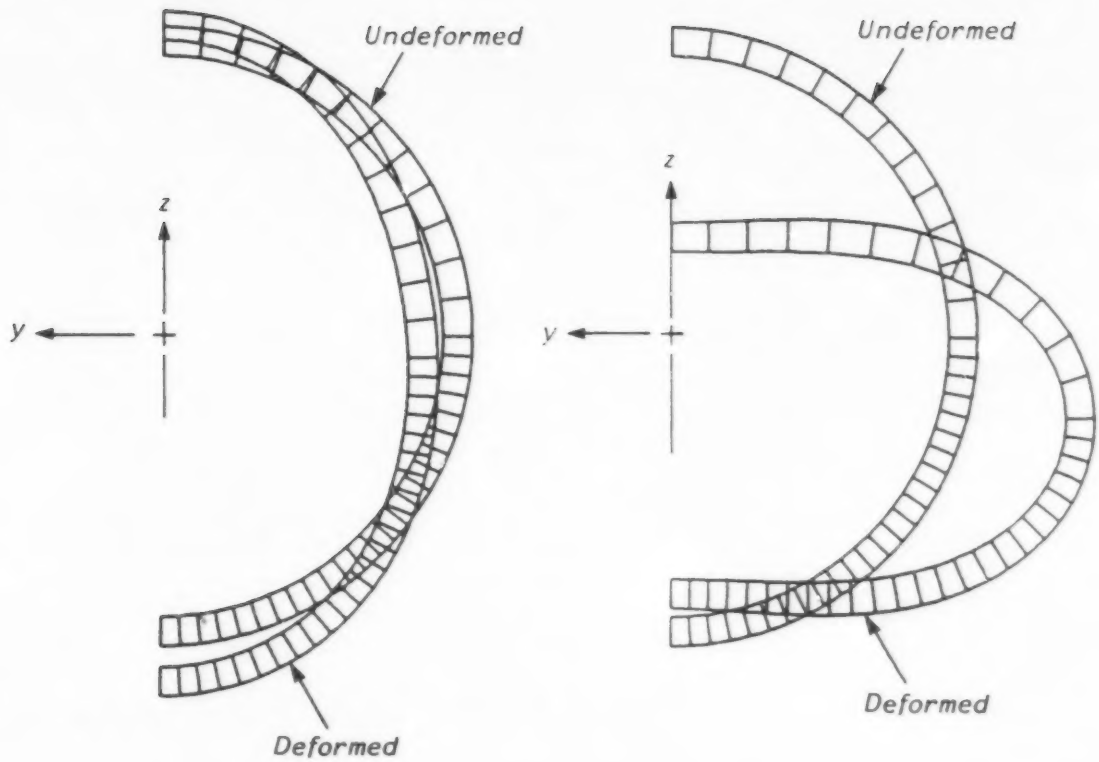


FIGURE 2
FINITE ELEMENT MODEL OF SURGE TANK



a) Half Full

b) Full

FIGURE 3
DEFORMED SHAPES OF TANK MID-SECTION DUE TO DEADWEIGHT LOADING AT TWO LIQUID LEVELS

TABLE 3

MAXIMUM STRESSES AT BLISTER LOCATIONS
(WALL THICKNESS = NOMINAL = 19.0 mm)

LOADING	*AXIAL STRESS (MPa)*	*HOOP STRESS (MPa)*
operating pressure (69 kPa)	2.949	4.603
design pressure (276 kPa)	11.796	18.412
deadweight (half full)	2.880	2.076
deadweight (full)	6.960	4.891

TABLE 4

MAXIMUM STRESSES AT BLISTER LOCATIONS
(WALL THICKNESS = NOMINAL - MAX. CORROSION = 12.7 mm)

LOADING	*AXIAL STRESS (MPa)*	*HOOP STRESS (MPa)*
operating pressure (69 kPa)	4.512	6.996
design pressure (276 kPa)	18.048	27.984
deadweight (half full)	4.116	2.211
deadweight (full)	10.224	6.465

Stresses used in the fracture evaluation are the sum of those arising from internal pressure (either operating or design) and deadweight (either half-full or full liquid level) loads.

7.0 *FRACTURE EVALUATION*

The fracture evaluation was based on the CEGB "R6" method/1-4/ in which margins on load or flaw size are obtained considering, simultaneously, the possibility of brittle fracture and plastic

collapse. (ie, the resulting safety margin will be less than that associated with either possibility considered individually).

The evaluation criteria used are similar to those of R6, Rev 1/1/:

1. no credit is taken for material resistance to stable tearing after crack initiation.

2. no detailed consideration of work hardening is included.

Refinement to account for either of these features is expected to elevate the resulting safety margin but with a significant (and probably unwarranted) increase in complexity.

The R6 procedure was computerized to study the sensitivity of safety margins to the various parameters influencing results. A synopsis of this study was given in Reference 7. Appendix B gives specific steps performed by the program.

The procedure requires that both the stress intensity factor, K, and limit load (for ligament rupture in this case), be calculated. The two defect models used are shown in Figure 4.

The calculated values establish the point "A" in Figure 5 which is compared to "B" on the assessment curve which depends on the material's toughness and flow stress. The ratio OB/OA is the safety margin.

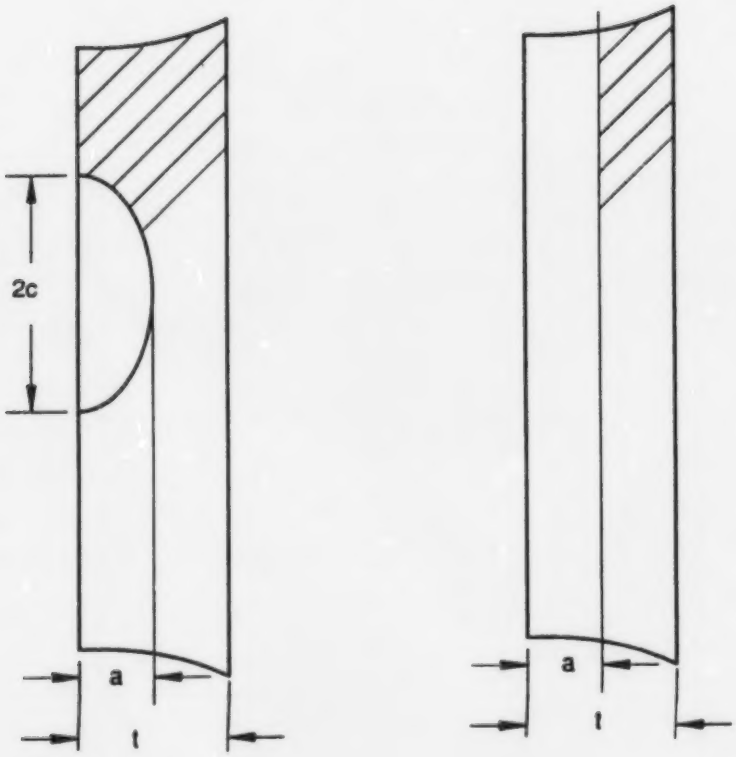
It is suggested that the most reasonable defect model is of a semielliptical crack no longer than that spanned by a blister (taken to be the diagonal distance across blister area #2: $2c = 290$ mm in Figure 4). Because available solutions do not exactly match the postulated defect model, the sensitivity of results was studied using:

i) K-solutions for finite and infinitely long, and two-dimensional (2D) crack models/11,13/.

ii) limit load solutions for semi-elliptical and 2D cracks in flat plates/13,14/.

8.0 *SAFETY MARGINS*

There is no ASME Code equivalent to Section XI (Rules for Inservice Inspection of Nuclear Power Plant Components/15/) applicable to non-nuclear components. Section XI (in IWB-3600) places limits on the stress intensity factor, K, and requires that the primary stress limits of Section III (the nuclear design code/16/) NB-3000 be satisfied considering a reduction of wall thickness due to the flaw.



Semi Elliptical

Infinitely Long (2D)

FIGURE 4

PART THROUGH-WALL FLAW MODELS

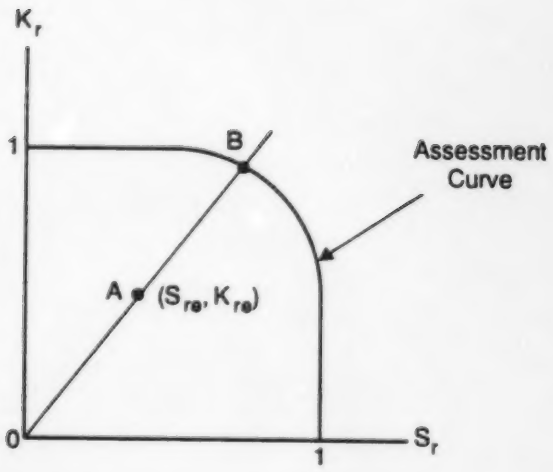


FIGURE 5

"R6" INTERACTION DIAGRAM

Plastic limit load analysis is permitted by SIII NB-3228 to show compliance with primary stress limits.

The R6 procedure examines both K and primary stress and is therefore equivalent in intent to the Section XI assessment procedure.

8.1 ***Primary Stress Limits***

The non-nuclear design code, Section VIII, Div 2/19/ ("design by analysis") is essentially the same as SIII. SVIII Div 1/18/ ("design by rule") gives simplified design procedures but accordingly imposes more stringent limits on primary stresses. The relevant limits are:

i) SIII and SVIII Div. 2: $P_m < \sigma_u/3$

ii) SVIII Div 1: $P_m < \sigma_u/4$

iii) SIII NB 3228.2: $P_m + P_b <$ 2/3 lower-bound collapse load.

(where P_m is the primary membrane stress, P_b is primary bending stress, σ_u is the ultimate tensile stress).

In contrast, the R6 procedure assesses primary stresses by comparison to a "flow stress":

$$\sigma_f = \tfrac{1}{2} (\sigma_y + \sigma_u)$$

(ie, the average of σ_y, the yield stress and σ_u the ultimate tensile stress). The value is intended to conservatively predict full scale test results/4/ but no explicit safety margin is recommended.

Table 5 compares the various allowable stresses. Requiring that a margin of 389.3/120.7 = 3.23 be applied to ligament rupture stress based on a flow stress calculated from the lowest measured yield and ultimate tensile stresses at 145°C/5/) yields the same margin as the SVIII Div 1 allowable of 4. Similarly, a margin of 389.3/155.1 = 2.51 is equivalent to the SIII and SVIII Div. 2 limits.

TABLE 5

YIELD, ULTIMATE TENSILE, "FLOW" AND ALLOWABLE STRESSES
FOR A516 Gr70 - MINIMUM SPECIFIED TENSILE STRENGTH IS 483 MPa (70 ksi)

TEMPERATURE		σ_y YIELD MPa	σ_u ULTIMATE MPa	σ_f FLOW MPa	S_m ALLOWABLE MPa	REFERENCE AND NOTES
°C	(°F)					
21	(70)	366.5	526.0	446.3	131.5	/5/, (1)
145	(293)	296.0	482.6	389.3	120.7	/5/, (1)
<343	(<650)	-	-	-	120.7	SVIII Div 1 (2)
38	(100)	-	-	-	160.6	SVIII Div 2 (3)
93	(200)	-	-	-	159.3	SVIII Div 2 (3)
149	(300)	-	-	-	155.1	SVIII Div 2 (3)

Note 1) flow stress = $(\sigma_y + \sigma_u)/2$; allowable based on $\sigma_u/4$, similar to SVIII-Div 1.
2) allowable based on $\sigma_u/4$, Table UCS-23/18/
3) allowable based on $\sigma_u/3$, Table ACS-1/19/ and Table I-1.1/17/
(Conversion factor: x ksi = 6.89476 x MPa)

A calculated plastic collapse load based on yield stress will lower-bound the actual collapse load/20/. Applying the required factor of 2/3 to that lower bound load is equivalent to a collapse load based on the R6 flow stress with a margin of 1.97 (ie, (2/3) 296.0 = 389.3/1.97).

Consequently, it is suggested that a safety margin of 3.23 on primary stress limits obtained using the R6 procedure is (for the present application) equivalent to the SVIII Div. 1 allowable stress, and more than required to satisfy the SIII and SVIII Div. 2 limits.

8.2 *Toughness Requirements*

Establishing a safety margin on toughness equivalent to SVIII Div. 1 is difficult since both design codes (SIII and SVIII) provide protection against brittle fracture by material selection rather than analysis/21/.

Explicit margins for assessment of defects in nuclear components are given in SXI IWB-3600:

i) $K < K_a/\sqrt{10}$ ("normal" and "upset" conditions)
ii) $K < K_{Ic}/\sqrt{2}$ ("emergency" and "faulted" conditions)

where K_a is the "arrest" toughness (ie, if a crack were to extend, it would stop if the stress intensity factor dropped below this value).

The more stringent of these implies a margin of $\sqrt{10} = 3.16$.

A valid K_{Ic} value could not be obtained in /5/ as a consequence of small specimen size and material ductility. The material exhibits resistance to crack extension after initiation.

9.0 *RESULTS*

A number of analyses were performed, based on various assumed wall thicknesses, stresses, flaw models, lengths and orientation to study the sensitivity of the calculation to these parameters.

The trends in the R6 assessment are as expected.

i) a decrease in safety margin with decreased allowable stress or toughness,

ii) a decrease in allowable flaw depth with wall thickness.

The effect of the postulated defect model may be less obvious. Appendix C (Tables C-13 and C-14) show allowable depths based on several candidates with the following results:

i) the allowable depth, based on semi-elliptical flaw models, decreases with the assumed flaw length.

ii) allowable depths based on hoop stress are less than those based on axial stress.

iii) when direct comparison is possible, the 2D defect model gives allowable depths equal or slightly lower than the "infinitely long" semielliptical model and always lower than the finite length semielliptical model.

Considering a maximum defect length equal to the diagonal dimension of the larger blister (290 mm), Table 6 gives allowable depths obtained using minimum properties and based on hoop stress due to internal pressure and full liquid level deadweight loads.

TABLE 6

ALLOWABLE DEFECT SIZES FOR VARIOUS SAFETY MARGINS BASED ON "R6" PROCEDURE (SEMI-ELLIPTICAL DEFECT MODEL - SEE FIGURE 4)

CASE	*ALLOWABLE DEPTHS [mm]*				*PRESSURE*	*WALL THICKNESS [mm]*
	SF=2	*3*	*3.3*	*4*		
2	17.1	17.1	17.1	17.1	operating	19.0
22	10.7	10.7	10.7	10.7	operating	12.7
7	16.9	15.8	15.5	14.7	design	19.0
27	10.5	9.3	9.0	8.1	design	12.7

Notes:
- stresses include internal pressure plus full liquid level deadweight loads.
- case numbers refer to Tables C-13 and C-14.
- depths given for Cases 2 and 22 actually represent the limit of validity of the equation used to calculate the stress intensity factor.

The two wall thicknesses correspond to the present conditions and for comparison, the minimum thickness having deducted the maximum corrosion allowance.

10.0 *CONCLUSIONS*

Table 6 gives allowable defect depths based on full liquid level deadweight loads plus either operating or design pressure for safety margins of 2, 3, and 4.

The margins are those evaluated using the CEGB "R6" procedure, based on lower case allowable stresses and initiation toughness, as measured for similar material/5/. The evaluation did not consider progressive or environmentally-enhanced time dependent damage mechanisms such as blister growth, corrosion or fatigue.

Section 7 of this report attempts to reconcile margins derived using the R6 procedure with ASME Section VIII Division 1, and concludes that a margin of 3.23 applied to flow stress as used in the R6 method is equivalent to SVIII's margin of 4.0 on ultimate tensile stress. It is not obvious how to establish an equivalent margin for toughness since in SVIII, protection against brittle fracture is provided by material selection. For comparison, SXI gives a factor of $\sqrt{10}$.

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APPENDIX A

FINITE ELEMENT DETAILS

Stress analysis results were obtained using a proprietary finite element code (ABAQUS version 4-8.5/20/).

The material was assumed to be isotropically elastic with an elastic modulus of 200 GPa and Poisson's ratio of 0.3.

Two sets of analysis were performed, one based on the nominal shell wall thickness, the other using the minimum thickness (ie, having deducted the maximum corrosion allowances). Several models were constructed with increasing mesh refinement to verify convergence of numerical results. Figure 2 shows the most refined of these. All models used second-order shell elements (ABAQUS type "S8R").

The models have two planes of symmetry: one through the ring stiffener mid-thickness, the other on the x-z plane (See Figure 2). Continuous vertical support was provided along the base of the support.

Three loading cases were considered:

i) internal pressure
ii) deadweight due to liquid level for a half-full tank
iii) deadweight for a full tank.

Deadweight loads were supplied by specifying a hydrostatic pressure varying linearly from zero at the liquid surface to P_{bot} at the tank bottom. Assuming the liquid has the same density as water, the following values are obtained:

TABLE A-1
HYDROSTATIC PRESSURES AT TANK BOTTOM DUE TO LIQUID LEVEL

LIQUID LEVEL	*DEPTH*		P_{bot}	
	m	*in*	*kPa*	*psi*
half full	1.219	48	11.95	1.75
full	2.438	96	23.90	3.47

Mesh generation, pre- and post-processing operations were performed using a variety of "in-house" computer programs.

APPENDIX B

DETAILED DESCRIPTION OF "R6" (REV 1) EVALUATION

References 1-3 describe several variants of the "R6" procedure for flaw assessment. This appendix describes in detail the variant applied to postulated flaws in the surge tank. The procedure was implemented as a FORTRAN program devised specifically for the surge tank.

In overview, the program solicits input to describe postulated tank and defect geometry, stresses, material properties. It then establishes the "evaluation point" (ie, the stress intensity factor and ligament stress) associated with the postulated conditions (Point 'A' in Figure 5). It then compares the evaluation point to permissible levels given by the assessment curve (Point B, Figure 5) which depend on the postulated material properties.

For a given flaw size, both stress intensity factor and net ligament stress are proportional to load, thus the safety margin is the ratio OB/OA.

The following information is required:

t_o original wall thickness (19.05 mm)
t_c wall thickness deduction for corrosion (0 to 6.35 mm)
D outer diameter (2.4765 m)

a flaw depth (see Figure 2)
2c flaw length (see Figure 2)

σ_p stress due to internal pressure (Tables 3 and 4)
σ_{DW} stress due to deadweight loads (Tables 3 and 4)

σ_y yield stress (Table 2)
σ_u ultimate tensile stress (Table 2)

J_c initiation toughness (40-100 kN/m)
E Young's modulus (192 GPa)
υ Poisson's ratio (0.3)

P internal pressure

The program then performs the following steps:

Step 1

Evaluate

$t = t_o - t_c$	wall thickness
$\sigma_f = (\sigma_y + \sigma_u)/2$	flow stress
$K_c = [EJ_c/(1-\upsilon^2)]^{1/2}$	initiation toughness
$\sigma_o = \sigma_p + \sigma_{DW} + P$	nominal stress

Step 2

Evaluate the stress intensity factor, K:

$$K = \sigma_o \, f\,(a/t) \sqrt{\pi a/Q}$$

For the semi-elliptical flow model/10/, Figure 4:

$$f(a/t) = M_1 + M_2\,(a/t)^2 + M_3\,(a/t)^4$$

$$M_1 = 1.13 - 0.09$$

$$M_2 = -0.54 + 0.89/(0.2 + a/c)$$

$$M_3 = 0.5 - 1.0/(0.65 + a/c) + 14\,(1 - a/c)^{24}$$

This expression is valid provided:

$$a/t < 0.75/(1 - 1.25\ t/c)$$

which limits application to crack depths of 75-90% of wall thickness, depending on defect length, c.

For the 2D crack model, $c \rightarrow \infty$ and, from a separate solution/13/:

$$f(a/t) = [\tan x)/x]^{1/2}\,[0.752 + 2.02\ a/t + 0.37\ (1-\sin x\ )^3]/\cos x$$

$$\text{where } x = \pi a/2t$$

This expression is valid for all crack depths:

$$0 < a/t < 1$$

The "shape factor" Q is /10/:

$$Q = 1.0 + 1.464\ (a/c)^{1.65}$$

Step 3

Evaluate the ligament stress:

$$\sigma = \sigma_o\ [1 - (a/t)/M][1 - a/t]^{-1}$$

where $M = [1 + 1.05\ c^2/Rt]^{1/2}$, an empirical "bulging" factor appropriate for axial part-through cracks in cylinders/11,12/ or a more conservative factor:

$$M = [1 + 2.0\ (c/t)^2]^{1/2}$$

intended for more "universal" application/12/. For the 2D model, $M \rightarrow \infty$.

Step 4

Obtain the evaluation point coordinates as ("A" in Figure 5):

$$S_{re} = \sigma/\sigma_f \text{ and } K_{re} = K/K_c$$

and obtain the point (S_r, K_r) at "B" on the assessment curve in Figure 5 from:

$$S_r = 2/\pi \arccos \exp(-\pi^2/8m^2);\ m = K_{re}/S_{re}$$

$$K_r = m \cdot S_r$$

The safety margin is given, alternatively, by

$$SM = K_r/K_{re} = S_r/S_{re} = (K_r^2 + S_r^2)^{1/2}/(K_{re}^2 + S_{re}^2)^{1/2}$$

APPENDIX C

DETAILED STRESS AND FRACTURE EVALUATION RESULTS

This appendix gives several tables which detail stresses near the two blister locations (Tables C-1 through C-12) and allowable defect depths for various assumed defect models and loading conditions (Table C-13 and C-14).

C-1 *Stresses*

Tables C-1 through C-6 give axial and hoop stresses for defect location #1. Each table gives results for a given wall thickness and loading. Node positions in each table are shown in Figure C-1; these cover the blister locations.

Tables C-7 through C-12 give similar results for defect location #2.

Defect #2, which is nearest the ring stiffener, experiences the higher stresses of the two. Maximum values are indicated by asterisks in Tables C-7 through C-12 and are repeated in Tables 3 and 4.

C-2 *Fracture Assessment*

A decrease in flow stress σ_f, or initiation toughness, J_c will decrease the allowable defect depth. However, the effect of assumed defect orientation and slope and loading may not be obvious. Tables C-13 and C-14 show the sensitivity of results to these parameters.

In many instances, allowable depths are indicated as being greater than some value because the K-solutions (see Appendix B, Step 2) are invalid beyond this depth.

TABLE C-1
BHWP PROCESS DRAIN SURGE TANK - AXIAL AND HOOP STRESSES
DEFECT #1 - INTERNAL PRESSURE (69 kPa) - WALL THICKNESS=19.1mm

NODE	AXIAL				HOOP			
	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]
1568	2.208	2.222	2.215	-0.007	4.399	4.429	4.414	-0.015
1570	2.214	2.214	2.214	0.000	4.409	4.417	4.413	-0.004
1580	2.206	2.219	2.213	-0.007	4.390	4.435	4.412	-0.022
1582	2.206	2.217	2.211	-0.006	4.395	4.429	4.412	-0.017
1588	2.210	2.222	2.216	-0.006	4.392	4.432	4.412	-0.020
1590	2.213	2.216	2.215	-0.002	4.409	4.417	4.413	-0.004
1596	2.211	2.223	2.217	-0.006	4.391	4.432	4.412	-0.021
1598	2.213	2.218	2.215	-0.003	4.407	4.417	4.412	-0.005
1602	2.207	2.220	2.213	-0.007	4.391	4.434	4.413	-0.022
1604	2.207	2.217	2.212	-0.005	4.396	4.429	4.413	-0.016
1608	2.206	2.221	2.213	-0.008	4.392	4.434	4.413	-0.021
1610	2.207	2.216	2.212	-0.004	4.397	4.430	4.413	-0.017
1620	2.202	2.219	2.210	-0.008	4.386	4.439	4.412	-0.026
1638	2.203	2.218	2.211	-0.008	4.388	4.438	4.413	-0.025
1644	2.204	2.217	2.211	-0.006	4.390	4.436	4.413	-0.023

TABLE C-2
BHWP PROCESS DRAIN SURGE TANK - AXIAL AND HOOP STRESSES
DEFECT #1 - HALF-FULL DEADWEIGHT LOADS - WALL THICKNESS=19.1mm

NODE	AXIAL				HOOP			
	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]
1568	-0.949	-1.878	-1.414	0.465	1.385	-1.187	0.099	1.286
1570	-0.866	-1.680	-1.273	0.407	1.209	-0.956	0.126	1.082
1580	-0.780	-1.433	-1.106	0.326	1.010	-0.690	0.160	0.850
1582	-0.659	-1.151	-0.905	0.246	0.797	-0.404	0.196	0.600
1588	-0.933	-1.844	-1.389	0.456	1.377	-1.182	0.097	1.279
1590	-0.857	-1.653	-1.255	0.398	1.203	-0.948	0.128	1.076
1596	-0.899	-1.829	-1.364	0.465	1.347	-1.150	0.099	1.249
1598	-0.840	-1.622	-1.231	0.391	1.186	-0.930	0.128	1.058
1602	-0.762	-1.406	-1.084	0.322	0.992	-0.672	0.160	0.832
1604	-0.641	-1.117	-0.879	0.238	0.771	-0.379	0.196	0.575
1608	-0.740	-1.374	-1.057	0.317	0.970	-0.649	0.160	0.809
1610	-0.621	-1.078	-0.849	0.228	0.742	-0.351	0.195	0.546
1620	-0.509	-0.835	-0.672	0.163	0.590	-0.119	0.235	0.355
1638	-0.490	-0.796	-0.643	0.153	0.560	-0.090	0.235	0.325
1644	-0.468	-0.754	-0.611	0.143	0.525	-0.059	0.233	0.292

TABLE C-3
BHWP PROCESS DRAIN SURGE TANK - AXIAL AND HOOP STRESSES
DEFECT #1 - FULL DEADWEIGHT LOADS - WALL THICKNESS=19.1mm

NODE	AXIAL				HOOP			
	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]
1568	1.806	3.958	2.882	-1.076	-2.744	4.278	0.767	-3.511
1570	2.001	4.119	3.060	-1.059	-2.562	4.211	0.825	-3.387
1580	2.244	4.245	3.245	-1.001	-2.351	4.101	0.875	-3.226
1582	2.466	4.351	3.408	-0.942	-2.057	3.911	0.927	-2.984
1588	1.848	4.004	2.926	-1.078	-2.792	4.339	0.774	-3.565
1590	2.063	4.184	3.124	-1.061	-2.629	4.271	0.821	-3.450
1596	1.856	4.126	2.991	-1.135	-2.817	4.347	0.765	-3.582
1598	2.116	4.258	3.187	-1.071	-2.680	4.318	0.819	-3.499
1602	2.284	4.313	3.298	-1.015	-2.392	4.140	0.874	-3.266
1604	2.505	4.403	3.454	-0.949	-2.082	3.936	0.927	-3.009
1608	2.317	4.387	3.352	-1.035	-2.436	4.185	0.875	-3.310
1610	2.546	4.452	3.499	-0.953	-2.108	3.966	0.929	-3.037
1620	2.688	4.409	3.549	-0.861	-1.704	3.663	0.980	-2.684
1638	2.722	4.447	3.584	-0.863	-1.715	3.675	0.980	-2.695
1644	2.749	4.489	3.619	-0.870	-1.723	3.686	0.982	-2.704

TABLE C-4
BHWP PROCESS DRAIN SURGE TANK - AXIAL AND HOOP STRESSES
DEFECT #1 - INTERNAL PRESSURE (69kPa) - WALL THICKNESS=12.7mm

NODE	AXIAL				HOOP			
	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]
1568	3.304	3.316	3.310	-0.006	6.609	6.637	6.623	-0.014
1570	3.319	3.302	3.311	0.009	6.631	6.608	6.619	0.012
1580	3.306	3.317	3.311	-0.005	6.590	6.646	6.618	-0.028
1582	3.308	3.315	3.312	-0.003	6.605	6.632	6.619	-0.013
1588	3.308	3.319	3.314	-0.005	6.588	6.647	6.617	-0.030
1590	3.316	3.309	3.312	0.003	6.630	6.608	6.619	0.011
1596	3.302	3.330	3.316	-0.014	6.588	6.646	6.617	-0.029
1598	3.315	3.313	3.314	0.001	6.627	6.610	6.619	0.009
1602	3.304	3.319	3.312	-0.007	6.593	6.645	6.619	-0.026
1604	3.309	3.314	3.311	-0.003	6.607	6.631	6.619	-0.012
1608	3.301	3.322	3.312	-0.010	6.596	6.645	6.620	-0.024
1610	3.309	3.312	3.311	-0.001	6.608	6.632	6.620	-0.012
1620	3.303	3.322	3.312	-0.010	6.587	6.650	6.619	-0.032
1638	3.303	3.320	3.311	-0.009	6.589	6.648	6.619	-0.030
1644	3.304	3.317	3.310	-0.007	6.595	6.645	6.620	-0.025

TABLE C-5
BHWP PROCESS DRAIN SURGE TANK - AXIAL AND HOOP STRESSES
DEFECT #1 - HALF-FULL DEADWEIGHT LOADS - WALL THICKNESS=12.7mm

NODE	AXIAL				HOOP			
	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]
1568	-1.607	-2.677	-2.142	0.535	1.645	-1.392	0.127	1.518
1570	-1.489	-2.397	-1.943	0.454	1.356	-1.013	0.171	1.184
1580	-1.377	-2.027	-1.702	0.325	1.050	-0.598	0.226	0.824
1582	-1.193	-1.611	-1.402	0.209	0.739	-0.169	0.285	0.454
1588	-1.579	-2.644	-2.112	0.532	1.651	-1.396	0.127	1.524
1590	-1.483	-2.363	-1.923	0.440	1.369	-1.018	0.176	1.193
1596	-1.516	-2.649	-2.082	0.566	1.620	-1.338	0.131	1.489
1598	-1.457	-2.329	-1.893	0.436	1.350	-0.998	0.176	1.174
1602	-1.349	-1.994	-1.671	0.323	1.031	-0.577	0.227	0.804
1604	-1.162	-1.559	-1.361	0.198	0.700	-0.131	0.284	0.416
1608	-1.310	-1.953	-1.632	0.322	1.002	-0.548	0.227	0.775
1610	-1.127	-1.498	-1.312	0.185	0.656	-0.090	0.283	0.373
1620	-0.954	-1.146	-1.050	0.096	0.461	0.234	0.348	0.114
1638	-0.917	-1.079	-0.998	0.081	0.410	0.283	0.346	0.063
1644	-0.877	-1.004	-0.941	0.063	0.354	0.334	0.344	0.010

TABLE C-6
BHWP PROCESS DRAIN SURGE TANK - AXIAL AND HOOP STRESSES
DEFECT #1 - FULL DEADWEIGHT LOADS - WALL THICKNESS=12.7mm

NODE	AXIAL				HOOP			
	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]
1568	3.055	5.455	4.255	-1.200	-2.897	5.260	1.182	-4.079
1570	3.264	5.703	4.484	-1.219	-2.692	5.219	1.263	-3.955
1580	3.605	5.891	4.748	-1.143	-2.469	5.141	1.336	-3.805
1582	3.914	6.084	4.999	-1.085	-2.120	4.942	1.411	-3.531
1588	3.143	5.608	4.376	-1.233	-3.007	5.380	1.186	-4.194
1590	3.417	5.867	4.642	-1.225	-2.843	5.351	1.254	-4.097
1596	3.165	5.902	4.534	-1.369	-3.074	5.411	1.168	-4.243
1598	3.547	6.052	4.800	-1.252	-2.942	5.442	1.250	-4.192
1602	3.706	6.071	4.888	-1.182	-2.568	5.231	1.332	-3.900
1604	4.013	6.230	5.121	-1.108	-2.187	5.005	1.409	-3.596
1608	3.786	6.271	5.028	-1.242	-2.660	5.329	1.335	-3.994
1610	4.127	6.357	5.242	-1.115	-2.250	5.077	1.413	-3.663
1620	4.241	6.220	5.231	-0.989	-1.686	4.659	1.487	-3.172
1638	4.323	6.338	5.331	-1.008	-1.728	4.701	1.486	-3.215
1644	4.394	6.462	5.428	-1.034	-1.761	4.740	1.490	-3.251

TABLE C-7
BHWP PROCESS DRAIN SURGE TANK - AXIAL AND HOOP STRESSES
DEFECT #2 - INTERNAL PRESSURE (69kPa) - WALL THICKNESS=19.1mm

NODE	AXIAL				HOOP			
	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]
930	1.490	2.949**	2.220	-0.729	3.948	4.425	4.186	-0.239
932	1.514	2.923	2.218	-0.705	3.936	4.440	4.188	-0.252
934	1.504	2.929	2.216	-0.713	3.966	4.418	4.192	-0.226
948	1.499	2.927	2.213	-0.714	3.959	4.428	4.194	-0.235
954	1.869	2.551	2.210	-0.341	4.376	4.584	4.480	-0.104
956	1.887	2.544	2.215	-0.329	4.348	4.603**	4.476	-0.127
958	1.885	2.545	2.215	-0.330	4.364	4.586	4.475	-0.111
962	2.140	2.296	2.218	-0.078	4.406	4.558	4.482	-0.076
964	2.154	2.276	2.215	-0.061	4.440	4.532	4.486	-0.046
966	2.156	2.272	2.214	-0.058	4.458	4.514	4.486	-0.028
970	1.880	2.545	2.213	-0.332	4.353	4.599	4.476	-0.123
976	2.150	2.275	2.212	-0.062	4.445	4.528	4.487	-0.042
1262	2.253	2.177	2.215	0.038	4.446	4.439	4.443	0.003
1264	2.237	2.193	2.215	0.022	4.425	4.458	4.441	-0.017
1266	2.240	2.186	2.213	0.027	4.441	4.442	4.442	0.000
1278	2.233	2.191	2.212	0.021	4.425	4.459	4.442	-0.017

TABLE C-8
BHWP PROCESS DRAIN SURGE TANK - AXIAL AND HOOP STRESSES
DEFECT #2 - HALF-FULL DEADWEIGHT LOADS - WALL THICKNESS=19.1mm

NODE	AXIAL				HOOP			
	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]
930	0.258	-2.880**	-1.311	1.569	2.076**	-1.161	0.458	1.619
932	0.143	-2.679	-1.268	1.411	1.929	-1.046	0.442	1.487
934	0.124	-2.490	-1.183	1.307	1.736	-0.876	0.430	1.306
948	0.039	-2.205	-1.083	1.122	1.526	-0.684	0.421	1.105
954	-0.381	-2.369	-1.375	0.994	1.377	-1.454	-0.039	1.415
956	-0.419	-2.201	-1.310	0.891	1.356	-1.345	0.006	1.350
958	-0.409	-2.036	-1.223	0.813	1.243	-1.145	0.049	1.194
962	-0.875	-1.994	-1.435	0.560	1.324	-1.419	-0.048	1.371
964	-0.818	-1.882	-1.350	0.532	1.231	-1.298	-0.013	1.245
966	-0.788	-1.722	-1.255	0.467	1.129	-1.072	0.029	1.101
970	-0.410	-1.808	-1.109	0.699	1.091	-0.903	0.094	0.997
976	-0.727	-1.529	-1.128	0.401	0.988	-0.833	0.078	0.910
1262	-1.044	-1.896	-1.470	0.426	1.335	-1.312	0.011	1.324
1264	-0.973	-1.790	-1.382	0.408	1.289	-1.195	0.047	1.242
1266	-0.913	-1.639	-1.276	0.363	1.162	-0.994	0.084	1.078
1278	-0.831	-1.446	-1.139	0.307	1.007	-0.757	0.125	0.882

TABLE C-9
BHWP PROCESS DRAIN SURGE TANK - AXIAL AND HOOP STRESSES
DEFECT #2 - FULL DEADWEIGHT LOADS - WALL THICKNESS=19.1mm

NODE	AXIAL				HOOP			
	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]
930	-2.535	6.644	2.055	-4.589	-4.891**	3.932	-0.479	-4.411
932	-2.049	6.734	2.343	-4.392	-4.720	3.975	-0.373	-4.347
934	-1.824	6.951	2.563	-4.388	-4.448	3.922	-0.263	-4.185
948	-1.386	6.960**	2.787	-4.173	-4.142	3.828	-0.157	-3.985
954	-0.572	4.853	2.141	-2.713	-2.656	4.768	1.056	-3.712
956	-0.180	4.960	2.390	-2.570	-2.696	4.843	1.074	-3.769
958	0.089	5.176	2.633	-2.544	-2.578	4.794	1.108	-3.686
962	0.941	3.537	2.239	-1.298	-2.350	4.532	1.091	-3.441
964	1.156	3.768	2.462	-1.306	-2.218	4.487	1.135	-3.352
966	1.446	3.957	2.702	-1.256	-2.128	4.477	1.175	-3.303
970	0.420	5.295	2.858	-2.437	-2.368	4.666	1.149	-3.517
976	1.700	4.142	2.921	-1.221	-1.955	4.373	1.209	-3.164
1262	1.467	3.176	2.321	-0.854	-2.357	4.139	0.891	-3.248
1264	1.656	3.410	2.533	-0.877	-2.357	4.210	0.926	-3.283
1266	1.900	3.628	2.764	-0.864	-2.227	4.168	0.970	-3.197
1278	2.135	3.822	2.978	-0.844	-2.045	4.077	1.016	-3.061

TABLE C-10
BHWP PROCESS DRAIN SURGE TANK - AXIAL AND HOOP STRESSES
DEFECT #2 - INTERNAL PRESSURE (69kPa) - WALL THICKNESS=12.7mm

NODE	AXIAL				HOOP			
	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]
930	2.131	4.512**	3.321	-1.191	6.171	6.922	6.547	-0.376
932	2.181	4.470	3.326	-1.145	6.110	6.996**	6.553	-0.443
934	2.174	4.480	3.327	-1.153	6.207	6.929	6.568	-0.361
948	2.171	4.470	3.320	-1.149	6.206	6.944	6.575	-0.369
954	3.046	3.559	3.302	-0.257	6.706	6.924	6.815	-0.109
956	3.087	3.538	3.312	-0.226	6.681	6.918	6.800	-0.119
958	3.087	3.550	3.319	-0.231	6.716	6.878	6.797	-0.081
962	3.313	3.310	3.312	0.002	6.628	6.730	6.679	-0.051
964	3.371	3.256	3.314	0.058	6.652	6.720	6.686	-0.034
966	3.372	3.259	3.315	0.057	6.692	6.679	6.686	0.006
970	3.085	3.553	3.319	-0.234	6.695	6.903	6.799	-0.104
976	3.364	3.269	3.316	0.048	6.667	6.704	6.686	-0.018
1262	3.383	3.242	3.313	0.071	6.610	6.628	6.619	-0.009
1264	3.348	3.277	3.313	0.036	6.596	6.641	6.618	-0.022
1266	3.363	3.262	3.312	0.050	6.634	6.604	6.619	0.015
1278	3.352	3.276	3.314	0.038	6.597	6.641	6.619	-0.022

TABLE C-11
BHWP PROCESS DRAIN SURGE TANK - AXIAL AND HOOP STRESSES
DEFECT #2 - HALF-FULL DEADWEIGHT LOADS - WALL THICKNESS=12.7mm

NODE	AXIAL				HOOP			
	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]
930	0.540	-4.116**	-1.788	2.328	2.211**	-1.726	0.243	1.969
932	0.246	-3.818	-1.786	2.032	2.091	-1.610	0.240	1.850
934	0.137	-3.580	-1.721	1.859	1.772	-1.271	0.251	1.521
948	-0.094	-3.169	-1.632	1.538	1.498	-0.925	0.287	1.211
954	-0.990	-2.847	-1.918	0.928	1.320	-1.796	-0.238	1.558
956	-1.097	-2.627	-1.862	0.765	1.276	-1.560	-0.142	1.418
958	-1.094	-2.490	-1.792	0.698	1.165	-1.268	-0.052	1.216
962	-1.594	-2.459	-2.026	0.433	1.371	-1.452	-0.040	1.411
964	-1.553	-2.340	-1.946	0.394	1.332	-1.305	0.014	1.319
966	-1.512	-2.187	-1.849	0.337	1.194	-1.037	0.079	1.115
970	-1.106	-2.249	-1.678	0.572	0.986	-0.906	0.040	0.946
976	-1.433	-1.982	-1.707	0.275	1.006	-0.699	0.153	0.853
1262	-1.678	-2.553	-2.115	0.438	1.594	-1.477	0.058	1.536
1264	-1.589	-2.440	-2.014	0.426	1.477	-1.260	0.108	1.368
1266	-1.541	-2.247	-1.894	0.353	1.294	-0.970	0.162	1.132
1278	-1.447	-2.008	-1.728	0.281	1.077	-0.633	0.222	0.855

TABLE C-12
BHWP PROCESS DRAIN SURGE TANK - AXIAL AND HOOP STRESSES
DEFECT #2 - FULL LIQUID LEVEL DEADWEIGHT LOADS - WALL THICKNESS=12.7mm

NODE	AXIAL				HOOP			
	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]	ID [MPa]	OD [MPa]	MEMBRANE [MPa]	BENDING [MPa]
930	-4.600	9.809	2.605	-7.205	-4.872	6.097	0.613	-5.484
932	-3.865	9.844	2.989	-6.854	-4.893	6.465**	0.786	-5.679
934	-3.632	10.224**	3.296	-6.928	-4.367	6.288	0.961	-5.328
948	-2.966	10.201	3.617	-6.583	-3.946	6.109	1.081	-5.028
954	0.320	5.259	2.790	-2.469	-1.888	6.161	2.136	-4.024
956	0.901	5.266	3.083	-2.183	-1.874	6.110	2.118	-3.992
958	1.209	5.668	3.439	-2.229	-1.824	6.121	2.148	-3.973
962	2.192	3.751	2.972	-0.779	-1.874	4.862	1.494	-3.368
964	2.492	4.015	3.254	-0.762	-1.975	5.084	1.554	-3.529
966	2.820	4.344	3.582	-0.762	-1.903	5.131	1.614	-3.517
970	1.650	5.917	3.783	-2.133	-1.588	5.984	2.198	-3.786
976	3.158	4.682	3.920	-0.762	-1.712	5.051	1.670	-3.381
1262	2.407	3.964	3.185	-0.778	-2.461	4.770	1.154	-3.615
1264	2.579	4.263	3.421	-0.842	-2.376	4.802	1.213	-3.589
1266	2.920	4.540	3.730	-0.810	-2.265	4.825	1.280	-3.545
1278	3.249	4.858	4.054	-0.805	-2.075	4.781	1.353	-3.428

TABLE C-13

ALLOWABLE FLAW DEPTHS FOR VARIOUS SAFETY MARGINS
BASED ON "R6" PROCEDURE
(Summary of Parametric Study)

All cases: - pressure plus full liquid level deadweight loads
- based on nominal wall thickness (19.0 mm)

CASE	ALLOWABLE DEPTHS [mm]				PRESSURE	STRESS	LENGTH [mm]	DEFECT MODEL
	SF=2	3	3.3	4				
1	17.1(a)	17.1(a)	17.1(a)	17.1(a)	op'g	hoop	290	RN/B
2	17.1(a)	17.1(a)	17.1(a)	17.1(a)	op'g	hoop	290	RN/C
3	14.2(a)	14.2(a)	14.2(a)	14.2(a)	op'g	hoop	inf.	RN/B
4	14.2(a)	14.2(a)	14.2(a)	14.2(a)	op'g	hoop	inf.	RN/C
5	16.3	15.6	15.4	14.9	op'g	hoop	-	2D
6	17.1(a)	17.1(a)	17.1(a)	17.1(a)	des.	hoop	290	RN/B
7	16.9	15.8	15.5	14.7	des.	hoop	290	RN/C
8	14.2(a)	13.2	12.7	11.9	des.	hoop	inf.	RN/B
9	14.2(a)	13.2	12.7	11.9	des.	hoop	inf.	RN/C
10	14.4	13.0	12.7	12.0	des.	hoop	-	2D
11	17.1(a)	17.1(a)	17.1(a)	17.1(a)	op'g	axial	290	RN/B
12	17.1(a)	17.1(a)	17.1(a)	17.1(a)	op'g	axial	290	RN/C
13	14.2(a)	14.2(a)	14.2(a)	14.2(a)	op'g	axial	inf.	RN/B
14	14.2(a)	14.2(a)	14.2(a)	14.2(a)	op'g	axial	inf.	RN/C
15	16.3	15.5	15.3	14.8	op'g	axial	-	2D
16	17.1(a)	17.1(a)	17.1(a)	17.1(a)	des.	axial	290	RN/B
17	17.1(a)	16.5	16.2	15.6	des.	axial	290	RN/C
18	14.2(a)	14.1	13.7	12.8	des.	axial	inf.	RN/B
19	14.2(a)	14.1	13.7	12.8	des.	axial	inf.	RN/C
20	15.0	13.8	13.5	12.8	des.	axial	-	2D

Notes: "op'g" - based on operating pressure (69 kPa)
"des." - based on design pressure (276 kPa)
"hoop" - based on hoop stresses (i.e. an axial crack model)
"axial" - based on axial stresses (i.e. circumferential crack)
"inf." - defect assumed to be infinitely long
"RN/B" - semi-elliptical flaw model (Raju-Newman solution /10/), "Battelle" /11,12/ bulging factor
"RN/C" - semi-elliptical flaw model, "Chell" /12/ bulging factor
" 2D " - two-dimensional defect model

Values marked "(a)" are maximum depths before exceeding validity limits of the expression used to calculate the stress intensity factor.

TABLE C-14

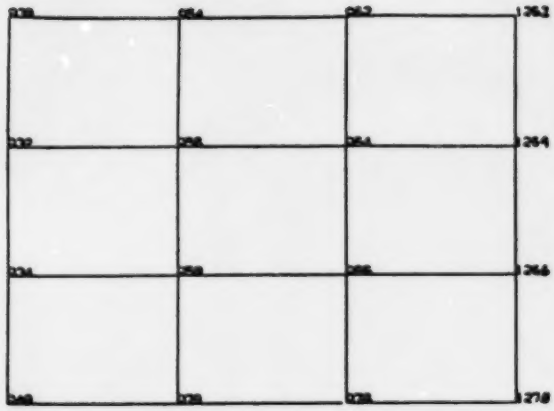
ALLOWABLE FLAW DEPTHS FOR VARIOUS SAFETY MARGINS
BASED ON "R6" PROCEDURE
(Summary of Parametric Study)

All cases: - pressure plus full liquid level deadweight loads
- based on wall thickness of 12.7 mm = nominal minus maximum corrosion allowance

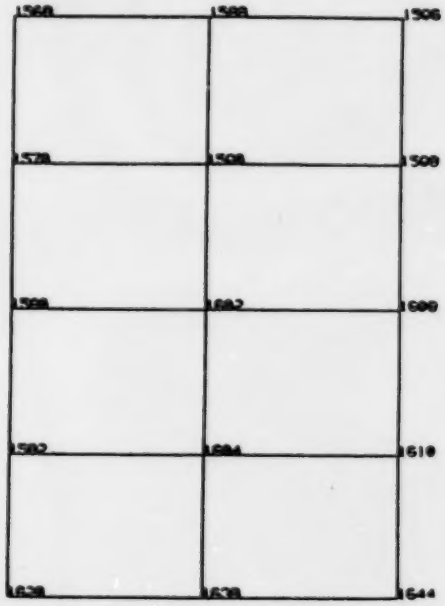
CASE	ALLOWABLE DEPTHS [mm]				PRESSURE	STRESS	LENGTH [mm]	DEFECT MODEL
	SF=2	3	3.3	4				
21	10.7(a)	10.7(a)	10.7(a)	10.7(a)	op'g	hoop	290	RN/B
22	10.7(a)	10.7(a)	10.7(a)	10.7(a)	op'g	hoop	290	RN/C
23	9.5(a)	9.5(a)	9.5(a)	9.5(a)	op'g	hoop	inf.	RN/B
24	9.5(a)	9.5(a)	9.5(a)	9.5(a)	op'g	hoop	inf.	RN/C
25	10.7	10.1	10.0	9.6	op'g	hoop	-	2D
26	10.7(a)	10.7(a)	10.5	9.6	des.	hoop	290	RN/B
27	10.5	9.3	9.0	8.1	des.	hoop	290	RN/C
28	9.3	8.0	7.7	7.1	des.	hoop	inf.	RN/B
29	9.3	8.0	7.7	7.1	des.	hoop	inf.	RN/C
30	9.1	8.1	7.8	7.2	des.	hoop	-	2D
31	10.7(a)	10.7(a)	10.7(a)	10.7(a)	op'g	axial	290	RN/B
32	10.7(a)	10.7(a)	10.7(a)	10.7(a)	op'g	axial	290	RN/C
33	9.5(a)	9.5(a)	9.5(a)	9.5(a)	op'g	axial	inf.	RN/B
34	9.5(a)	9.5(a)	9.5(a)	9.5(a)	op'g	axial	inf.	RN/C
35	10.6	10.0	9.8	9.4	op'g	axial	-	2D
36	10.7(a)	10.7(a)	10.7(a)	10.5	des.	axial	290	RN/B
37	10.7(a)	10.0	9.7	9.0	des.	axial	290	RN/C
38	9.5(a)	8.7	8.4	7.8	des.	axial	inf.	RN/B
39	9.5(a)	8.7	8.4	7.8	des.	axial	inf.	RN/C
40	9.5	8.6	8.4	7.8	des.	axial	-	2D

Notes: "op'g" - based on operating pressure (69 kPa)
"des." - based on design pressure (276 kPa)
"hoop" - based on hoop stresses (i.e. an axial crack model)
"axial" - based on axial stresses (i.e. circumferential crack)
"inf." - defect assumed to be infinitely long
"RN/B" - semi-elliptical flaw model (Raju-Newman solution /10/), "Battelle" /11,12/ bulging factor
"RN/C" - semi-elliptical flaw model, "Chell" /12/ bulging factor
" 2D " - two-dimensional defect model

Values marked "(a)" are maximum depths before exceeding validity limits of the expression used to calculate the stress intensity factor.



Blister Location #2



Blister Location #1

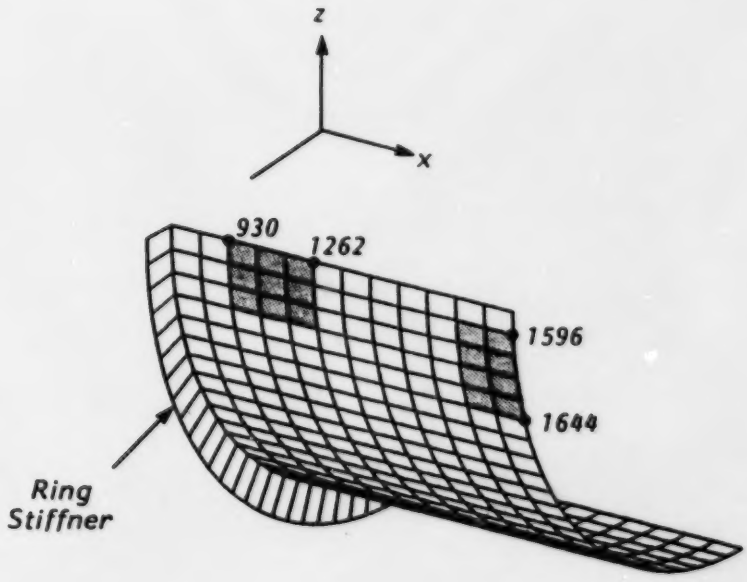


FIGURE C-1
NODE POSITIONS IN TABLES C-1 THROUGH C-12 CORRESPONDING TO BLISTER LOCATIONS